Automatische Transitionsvorhersage im DLR *TAU* Code Status der Entwicklung und Validierung

Automatic Transition Prediction in the DLR *TAU* Code - Current Status of Development and Validation

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Outline

- Introduction
- Different Coupling Approaches
- Transition Prediction Coupling Structure
- Computational Results
  - 2D two-element configuration
  - 2D three-element configuration
  - 3D generic aircraft configuration (very brief)
- Conclusion & Outlook

Introduction

- Background of considering transition in RANS-based CFD tools
  - Better numerical simulation results
    - Capturing of physical phenomena, which were discounted otherwise
    - Quantitatively, sometimes even qualitatively the results can differ significantly w/o transition
    - Influence on lift and drag, pressure and skin friction distribution
- Long term requirement from research organisations and industry
  - Possibility of general transition prescription
  - Some kind of transitional flow modelling
  - Transition prediction
  - Automatically: no intervention by the code user
  - Autonomously: as little additional information as possible
  - Multi-element wing configurations

Introduction

- Main objectives of the functionality today
  - Improved simulation of interaction between transition and separation
  - Exploitation of the full potential of advanced turbulence models
- Applications areas today
  - EU- and DLR-Projects
    - INROS (Design of helicopter airfoils)
    - SIMCOS (Dynamic Stall)
    - iGREEN (Shock buffet of laminar wings)
    - TELFONA (*N* factors of ETW)
  - Design of high lift systems with long laminar boundary layers (EL II)
  - Cruise configurations (Lufo IV-Aeronext, Wing stall investigation)
  - Performance of sailplanes (laminar length on fuselage up to 20%)
  - Future laminar wing of a transport aircraft

- **Different coupling approaches:**
  - RANS solver + stability code + e^N method
  - RANS solver + boundary layer code + stability code + e^N method
  - RANS solver + boundary layer code + e^N database method(s)
  - RANS solver + transition closure model or transition/turbulence model

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  - RANS solver + stability code + e^N method
  - RANS solver + boundary layer code
    + stability code + e^N method
  - RANS solver + boundary layer code
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  - RANS solver + transition closure model or
    transition/turbulence model

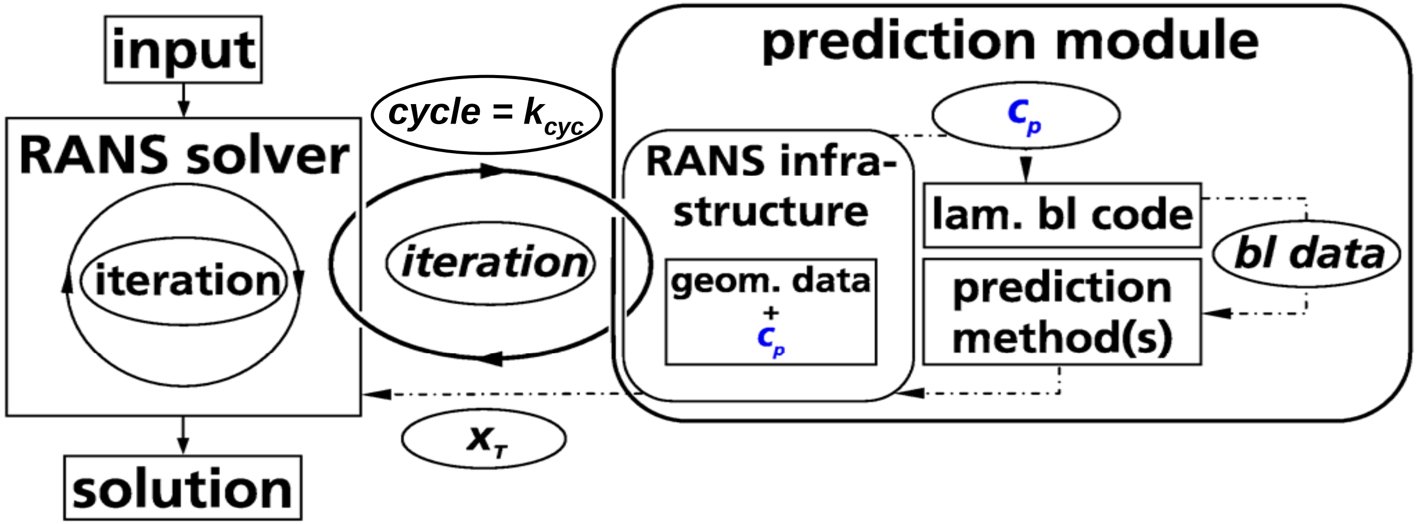
- Different coupling approaches:
  - RANS solver + stability code + e^N method
  - RANS solver + boundary layer code
+ fully automated stability code
+ e^N method
  - RANS solver + boundary layer code
+ e^N database method(s)
  - RANS solver + transition closure model or
transition/turbulence model

- Different coupling approaches:

  - RANS solver + fully automated stability code + e^N method ← 2
  - RANS solver + boundary layer code + fully automated stability code + e^N method ← 1
  - RANS solver + boundary layer code + e^N database method(s) ← 3
  - RANS solver + transition closure model or transition/turbulence model ← future

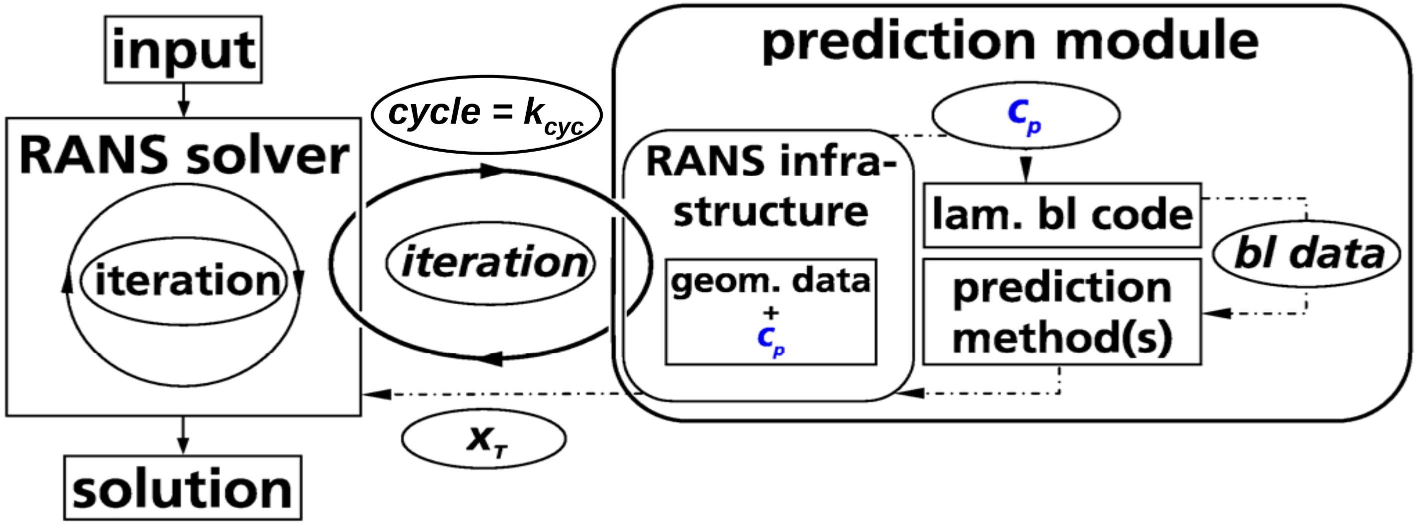
Transition Prediction Coupling Structure

external BL approach

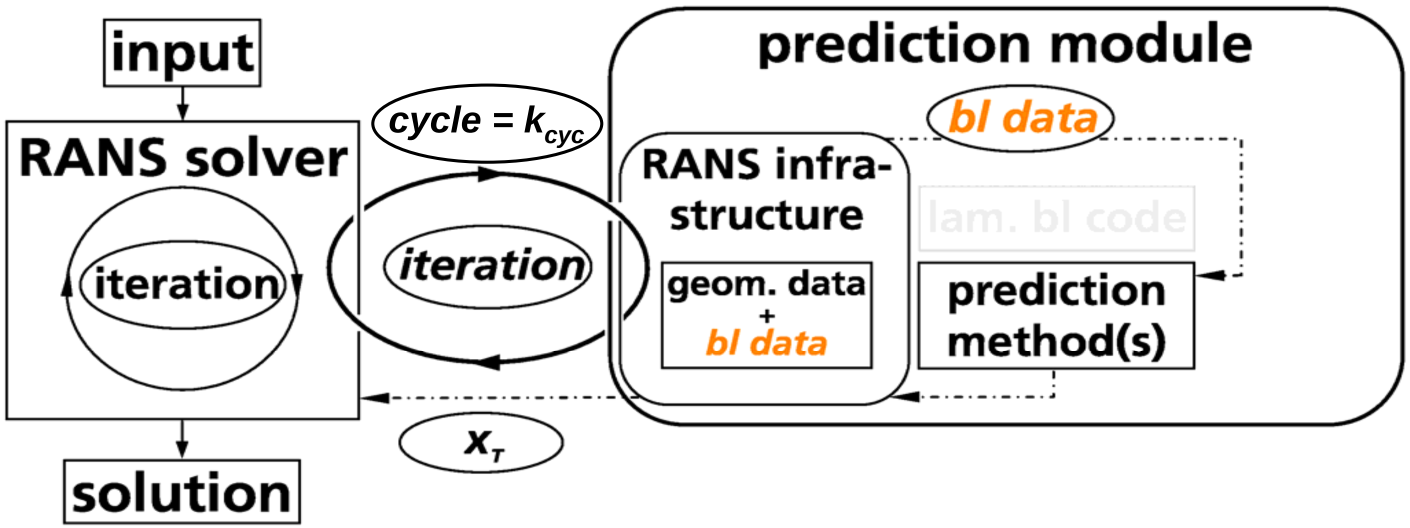


Transition Prediction Coupling Structure

external BL approach



internal BL approach



Transition prediction module

transition module

- line-in-flight cuts

  or
- inviscid stream lines

- ***c_p-extraction***

  or
- lam. BL data from RANS grid

- ***lam. BL code COCO***
  - swept, tapered → conical flow, 2.5d
  - streamline-oriented
  - external code

- local lin. stability code LILO
  - e^N method for TS & CF
  - external code

  or
- e^N database methods
  - one for TS & one for CF
  - external codes

Transition prediction module

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RANS infrastructure

- *c_p-extraction*
  or
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Possible combinations currently available

transition module

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2D

Possible combinations currently available

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  or
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- lam. BL data from RANS grid

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  - e^N method for TS & CF
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  or
- e^N database methods
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3D

Application areas

- 2d airfoil configurations
- 2.5d wing configurations: inf. swept
- 3d wing configurations
- 3d fuselages
- 3d nacelles

- Single-element configurations
- Mulit-element configurations

- Flow topologies
  - attached
  - with lam. separation:
    - LS point as transition point
    - real stability analysis with stability code inside bubble
    + many points in prismatic layer

Application areas

- 2d airfoil configurations
- 2.5d wing configurations: inf. swept
- 3d wing configurations
- 3d fuselages
- 3d nacelles

streamlines necessary!

- Single-element configurations
- Mulit-element configurations

- Flow topologies
  - attached
  - with lam. separation:
    - LS point as transition point
    - real stability analysis with stability code inside bubble

    + many points in prismatic layer

lam. BL data from RANS grid needed!
for 3d case: for CF
$\rightarrow$ 128 points in wall normal direction necessary!!!

Application areas

- 2d airfoil configurations
- 2.5d wing configurations: inf. swept
- 3d wing configurations
- 3d fuselages
- 3d nacelles

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    - real stability analysis with stability code inside bubble + many points in prismatic layer

Algorithm

- **set s_{tr}^{u} and s_{tr}^{l} far downstream** ($\rightarrow$ start mit quasi fully-laminar conditions)
- **compute flow field**
- **check for lam. separation in RANS grid**
  - $\rightarrow$ **set laminar separation points as new $s_{tr}^{u,l}$**
  - $\Rightarrow$ stabilization of the computation in the transient phase
- $c_l \approx const.$ in cycles
  - $\rightarrow$ **call transition module**
  - $\rightarrow$ **use** **a.) new transition point directly**
    or
    b.) lam. separation point of BL code as approximation
- **see new $s_{tr}^{u,l}$ underrelaxed** $\rightarrow$ $s_{tr}^{u,l} = s_{tr}^{u,l}\,\delta, \quad 1.0 < \delta < 1.5$
  $\Rightarrow$ damping of oscillations in transition point iteration

Algorithm

- **set s_{tr}^{u} and s_{tr}^{l} far downstream** ($\rightarrow$ start mit quasi fully-laminar conditions)
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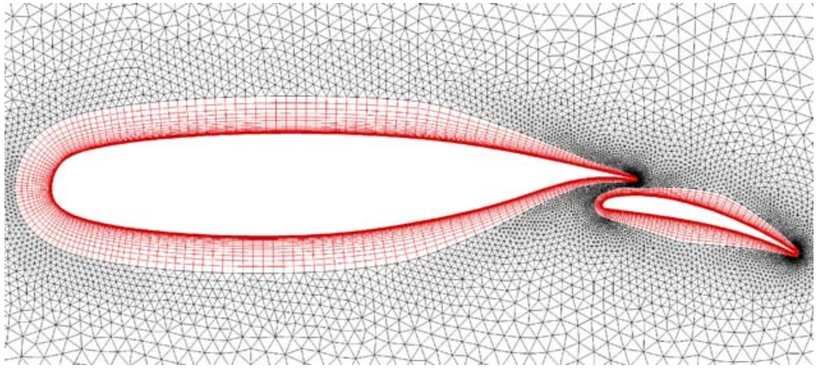
  - $\Rightarrow$ damping of oscillations in transition point iteration
- **check convergence** $\rightarrow$ $\Delta s_{tr}^{u,l} < \varepsilon$

no — **yes** $\rightarrow$ ***STOP***

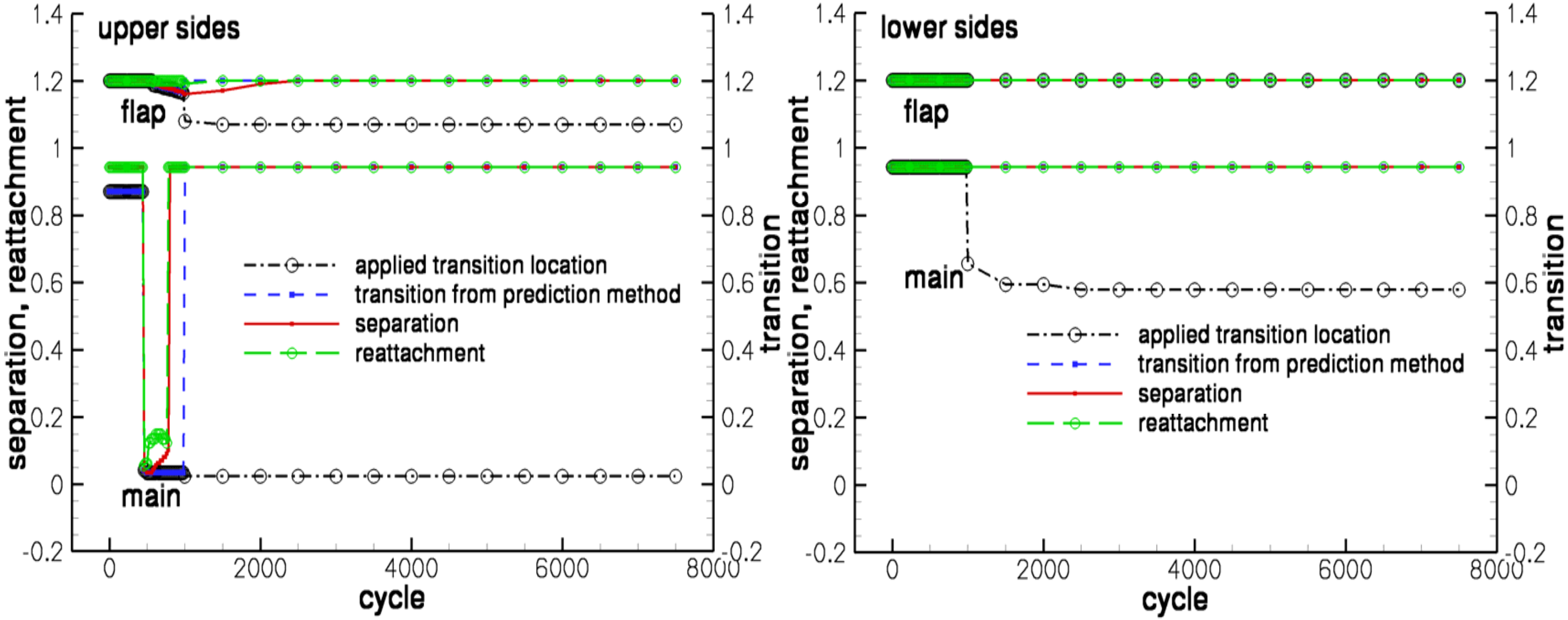
Computational Results

- **2d two-element configuration:**
  - **NLR 7301 with flap**
  - **gap: 2.6% c_{main}, $c_{flap}/c_{main} = 0.34$**
  - **M = 0.185, Re = 1.35 x 10^6, α = 6.0°**
  - **grid: 23,000 triangles + 15,000 quadriliterals**
    on contour: main → 250, flap → 180, 36 in both prismatic layers
  - **SAE**
  - **N_{TS} = 9.0 (arbitrary setting)**
  - **exp. transition locations: upper → main: 3.5% & flap: 66.5%**
    lower → main: 62.5% & flap: fully laminar
  - **different mode combinations:**
    a) laminar BL code & stability code → BL mode 1
    b) laminar BL inside RANS & stability code → BL mode 2



grid: Airbus

Transition iteration convergence history: BL mode 1

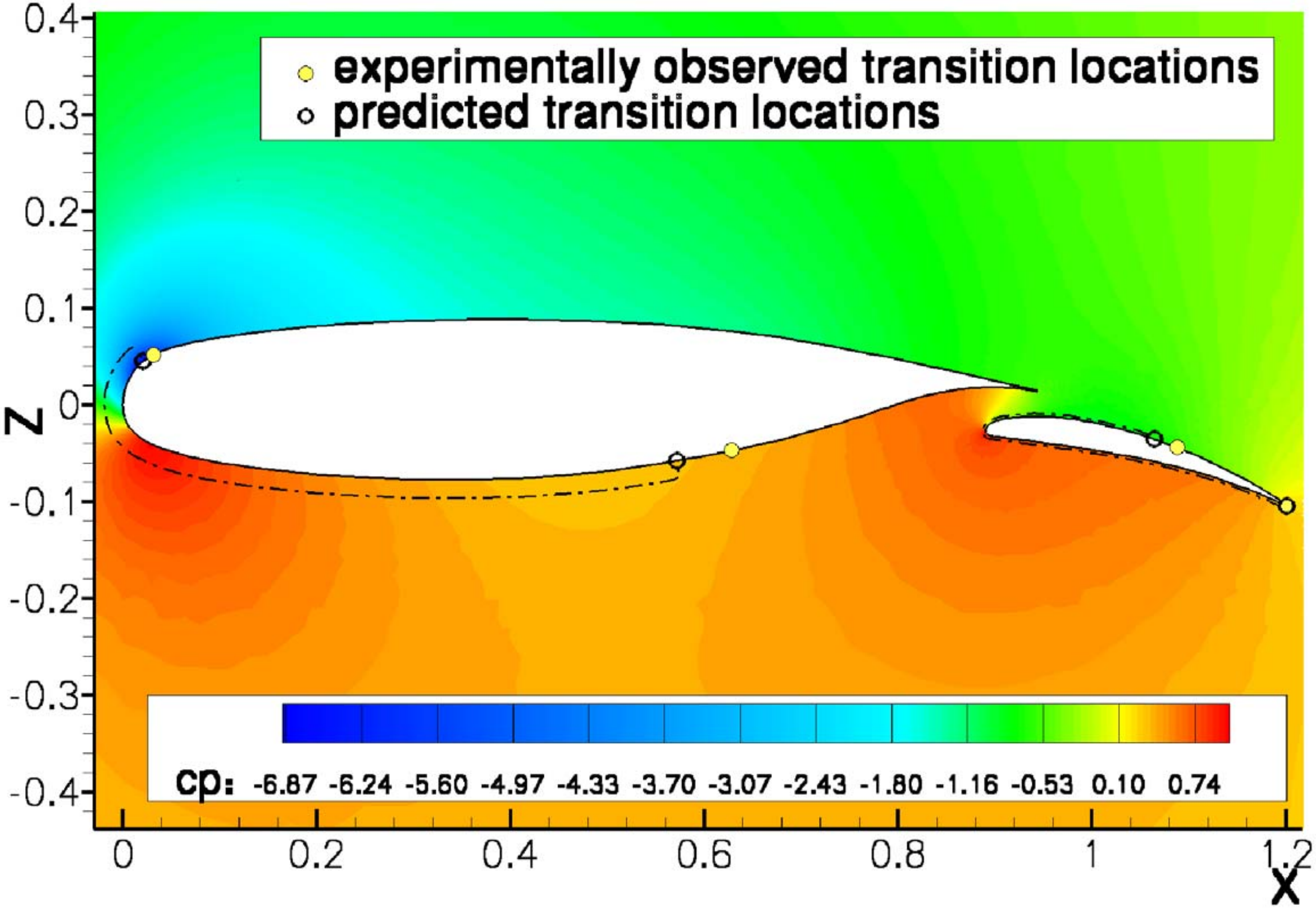


- **pre-prediction phase** → **1,000 cycles**
  every 20 cycles
- **prediction phase** → **starts at cycle = 1,000**
  every *500* cycles

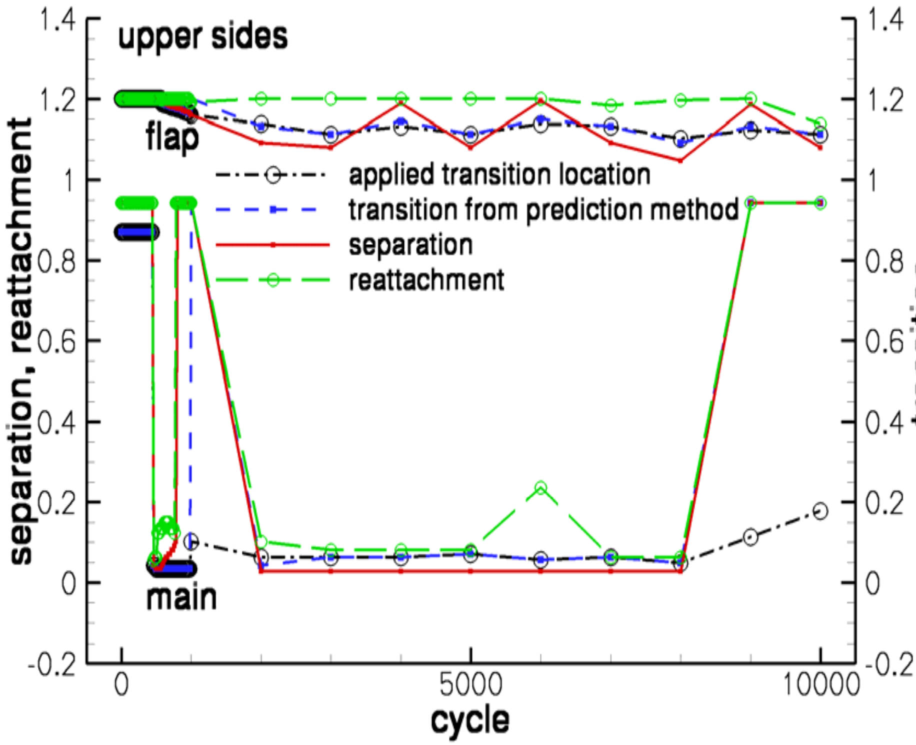
- **very fast convergence**

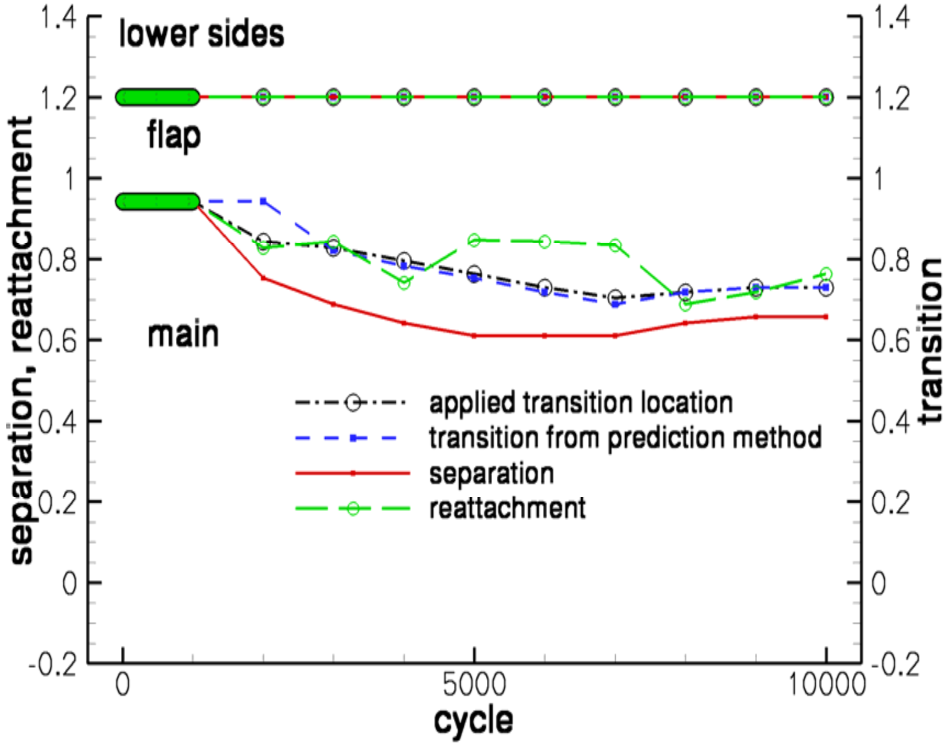
c_p-field and transition points: BL mode 1

- all transition points *up-stream* of experimental values
- *no* separation in final RANS solution
- good approximation of the measured transition points



Transition iteration convergence history: BL mode 2, run a

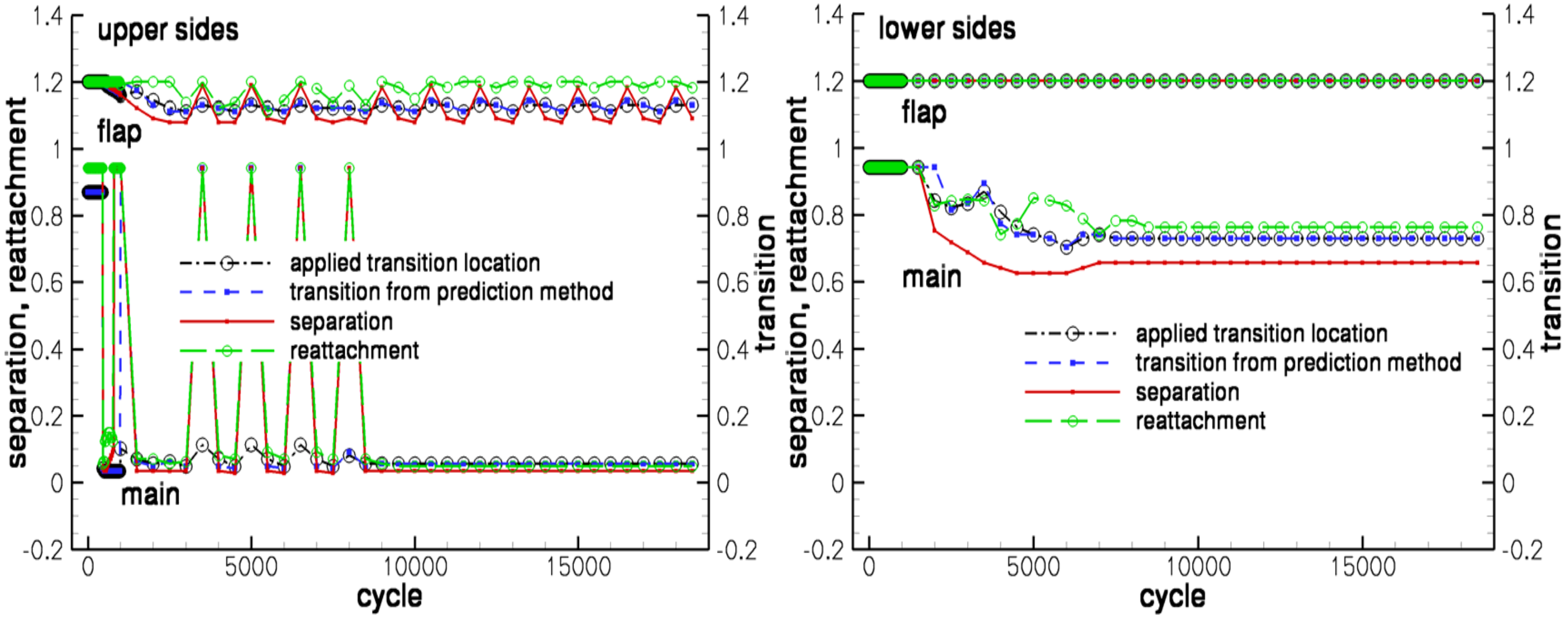




- pre-prediction phase → 1,000 cycles
  every 20 cycles
- prediction phase → starts at cycle = 1,000
  every *1,000* cycles
  stops at cycle = 10,000

- no convergence
- 1st numerical instability on flap
  → induced by transition iteration
- 2nd numerical instability on main
  → induced by RANS procedure

Transition iteration convergence history: BL mode 2, run b

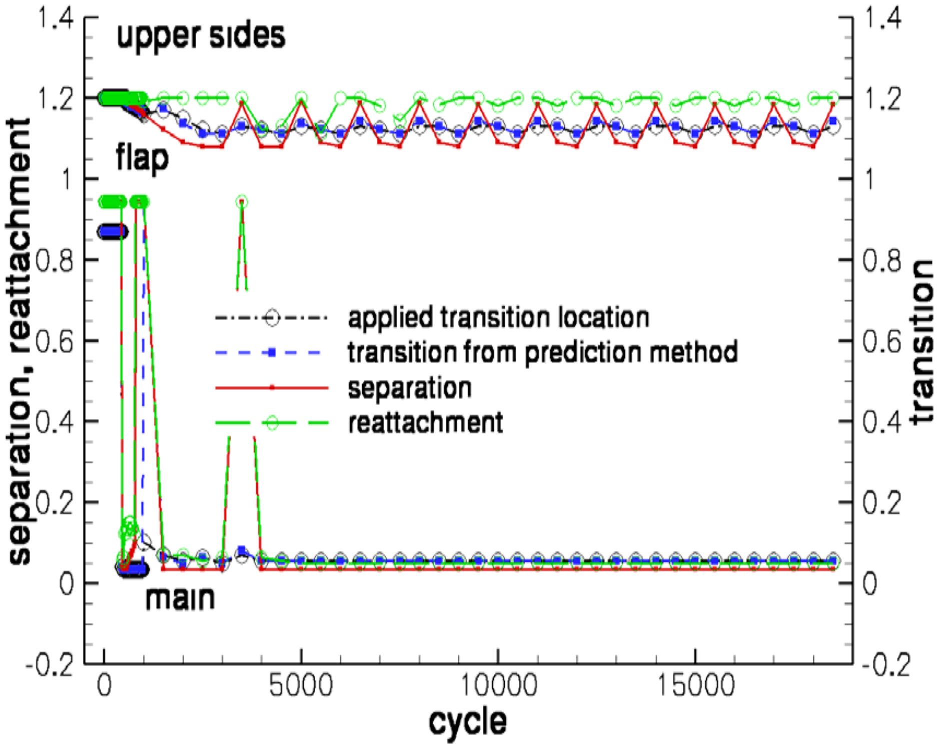


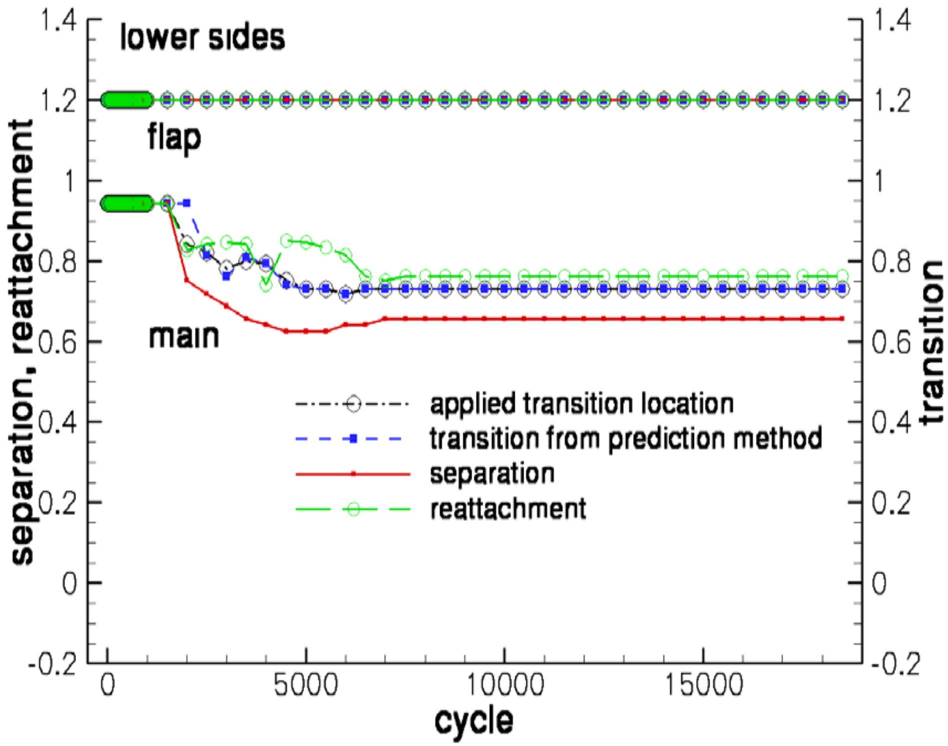
- **pre-prediction phase → 1,000 cycles every 20 cycles**
- **prediction phase → starts at cycle = 1,000 every *500* cycles**

- **limited convergence**
- **1st numerical instability on flap → remains**
- **2nd numerical instability on main → damped by the procedure**

Transition iteration convergence history: BL mode 2, run b

new



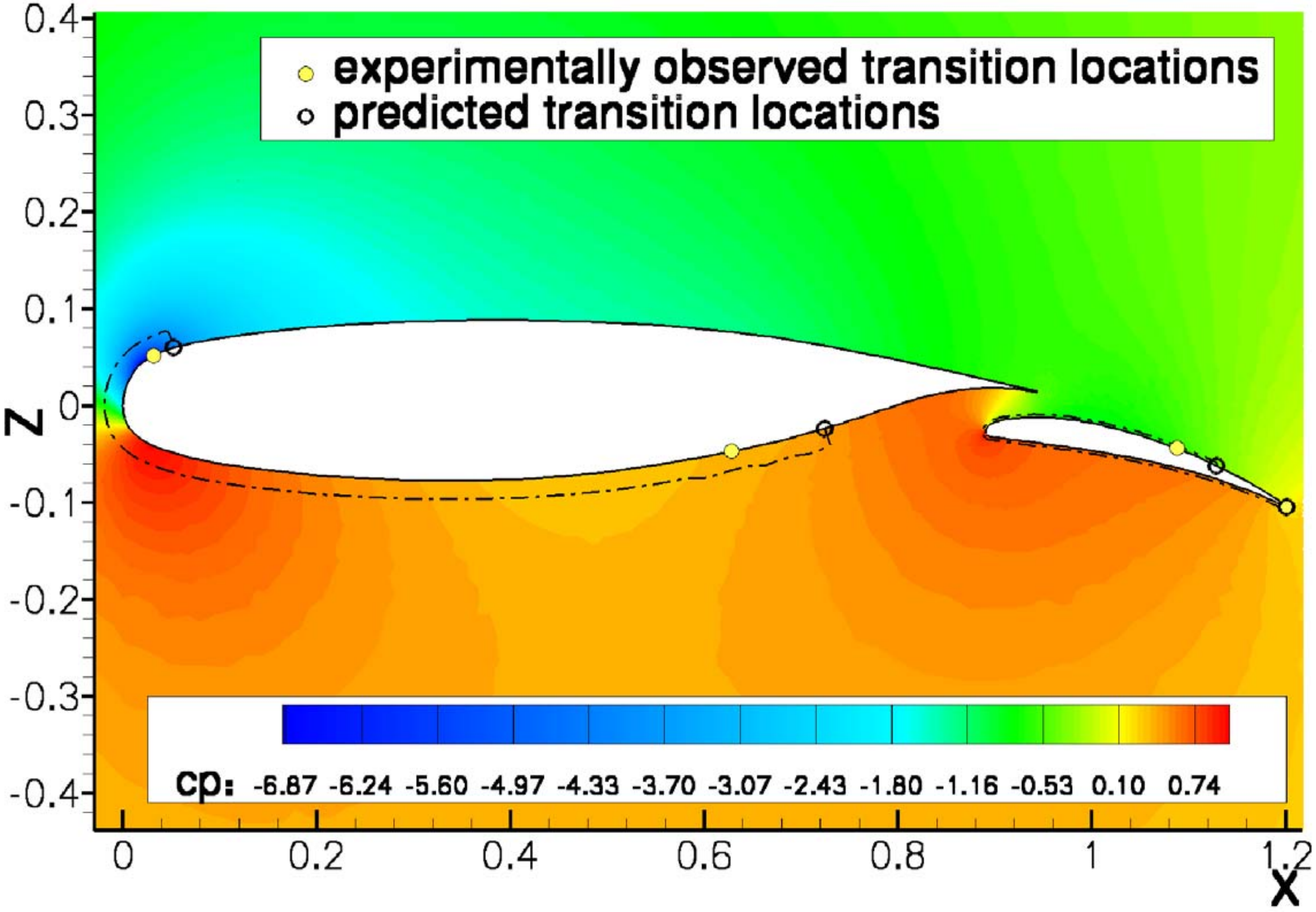


- pre-prediction phase → 1,000 cycles
  every 20 cycles
- prediction phase → starts at cycle = 1,000
  every *500* cycles

- limited convergence
- 1st numerical instability on flap
  → remains
- 2nd numerical instability on main
  → damped *faster* by the procedure

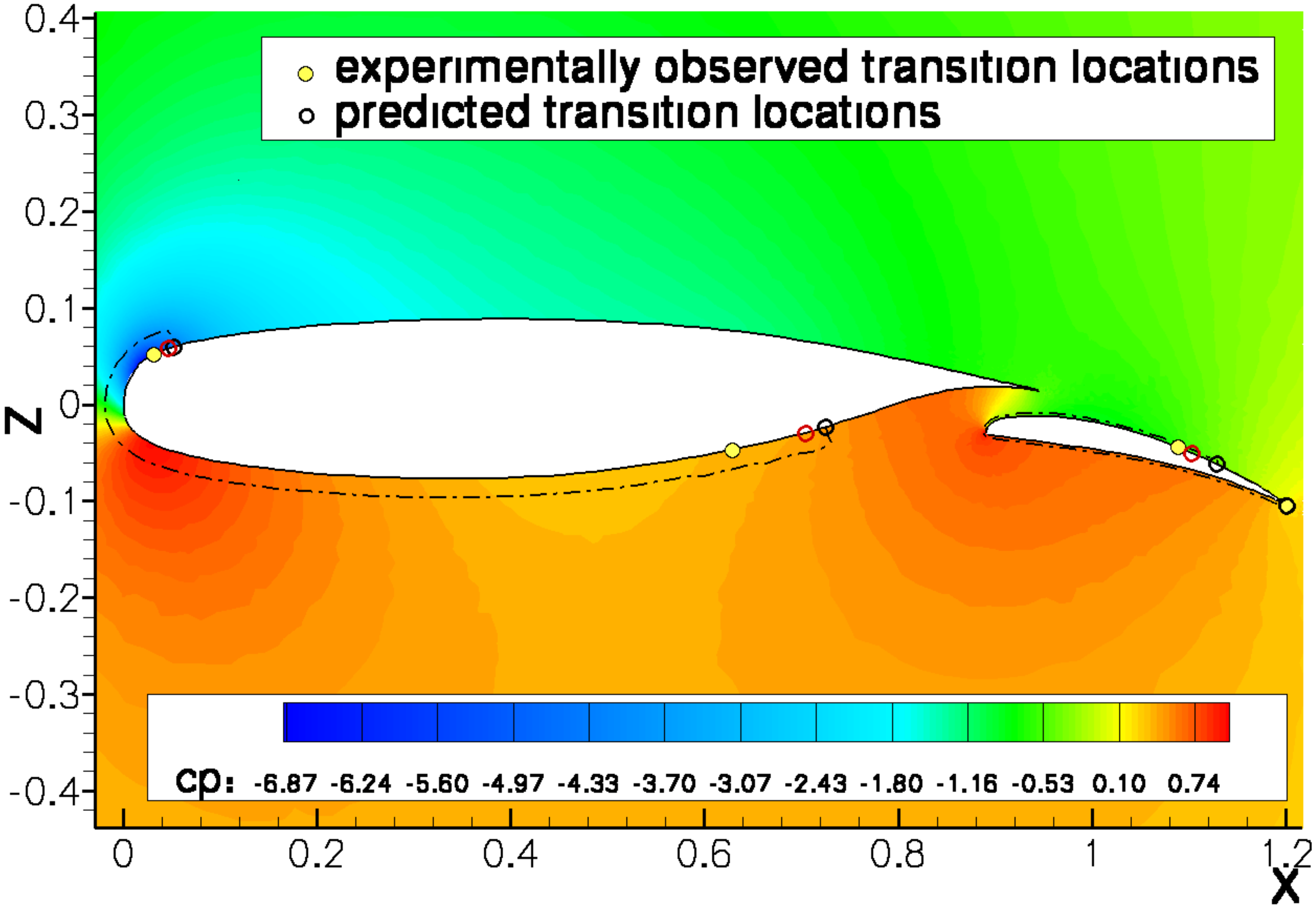
c_p-field and transition points: BL mode 2

- all transition points *down-stream* of experimental values
- *two* separa-tions in final RANS solu-tion
- flap separa-tion oscilla-tion remains
- improved transition lo-cations using calibrated *N* factor
- *individual, au-tomatic shut-down of tran-sition module necessary*

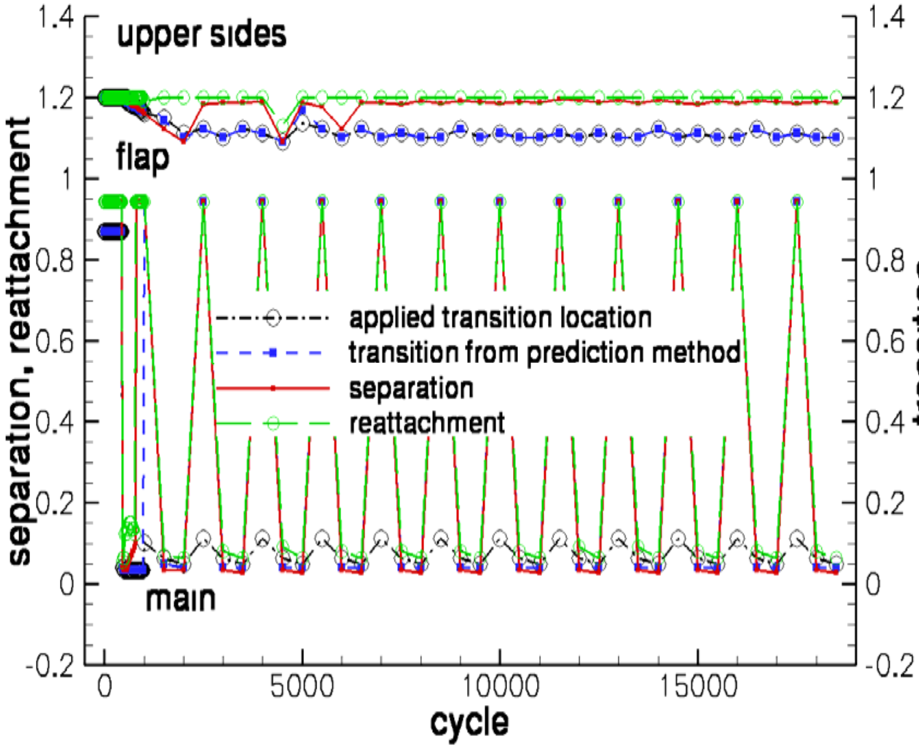


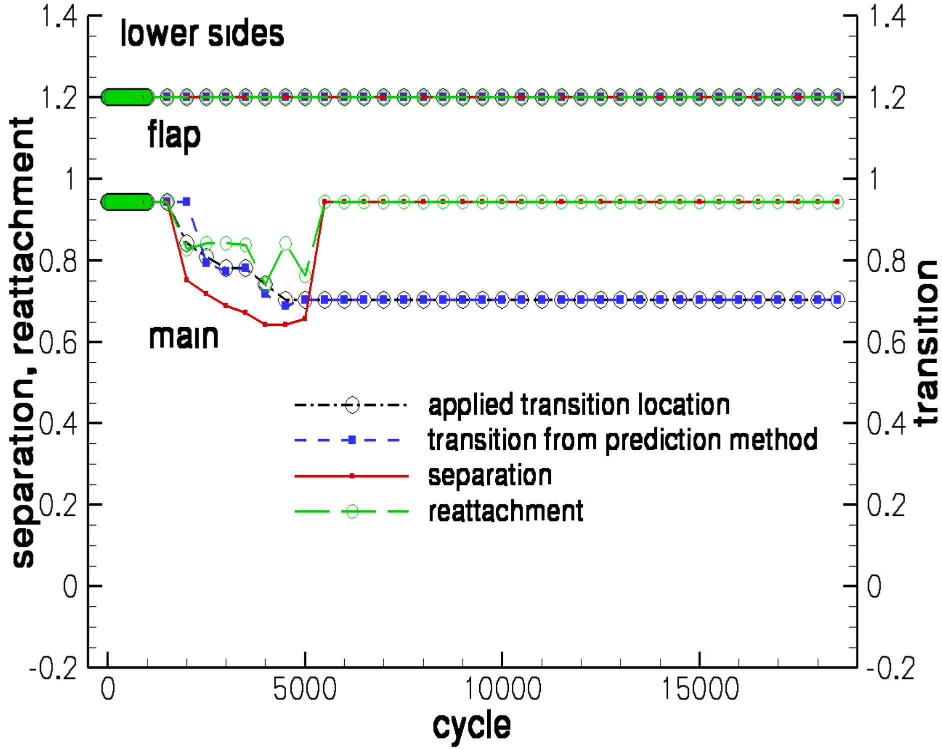
c_p-field and transition points: BL mode 2

- all transition points *down-stream* of experimental values
- *two* separa-tions in final RANS solu-tion
- flap separa-tion oscilla-tion remains
- **improved transition lo-cations using calibrated *N* factor *N* = 5.8**
- *individual, au-tomatic shut-down of tran-sition module necessary*



Transition iteration convergence history: BL mode 2, N = 5.8

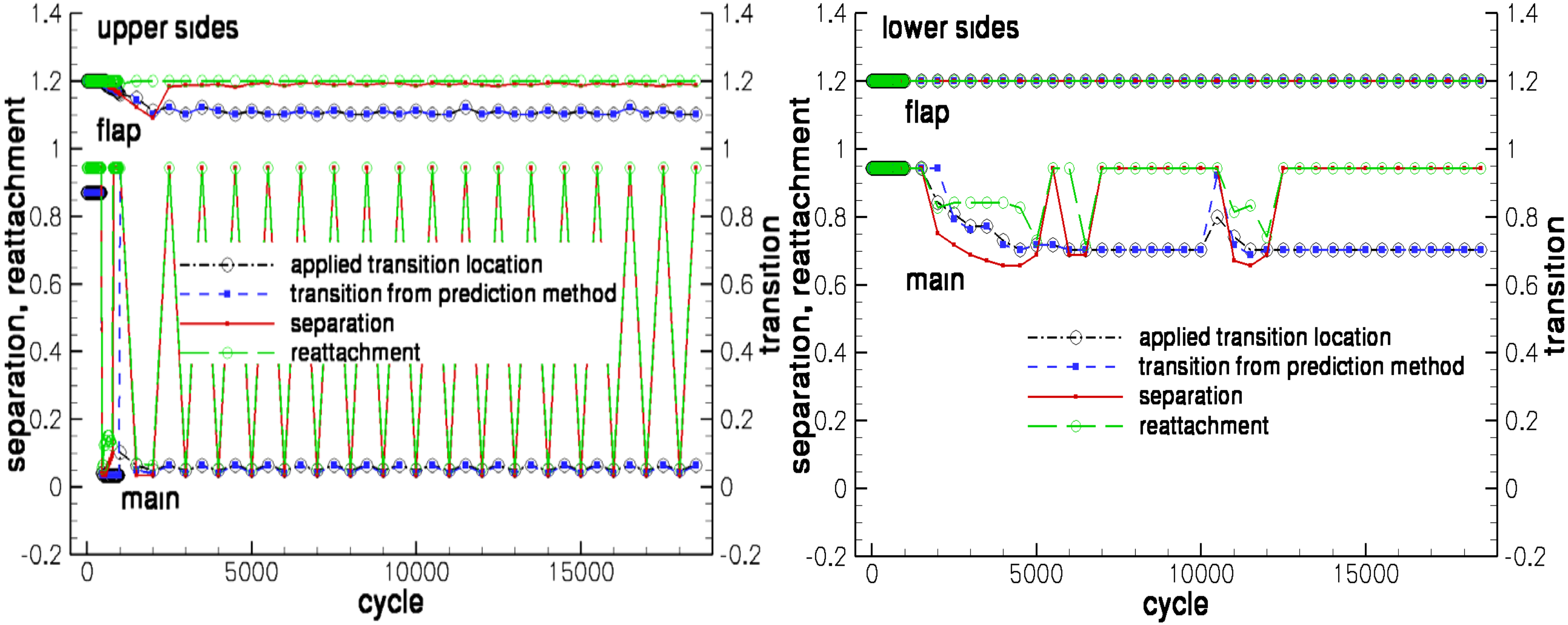




- **pre-prediction phase** → **1,000 cycles**
  every 20 cycles
- **prediction phase** → **starts at cycle = 1,000**
  every *500* cycles

- **limited convergence**
- **1st numerical instability on flap**
  → **small and acceptable**
- **2nd numerical instability on main**
  → **NOT damped**

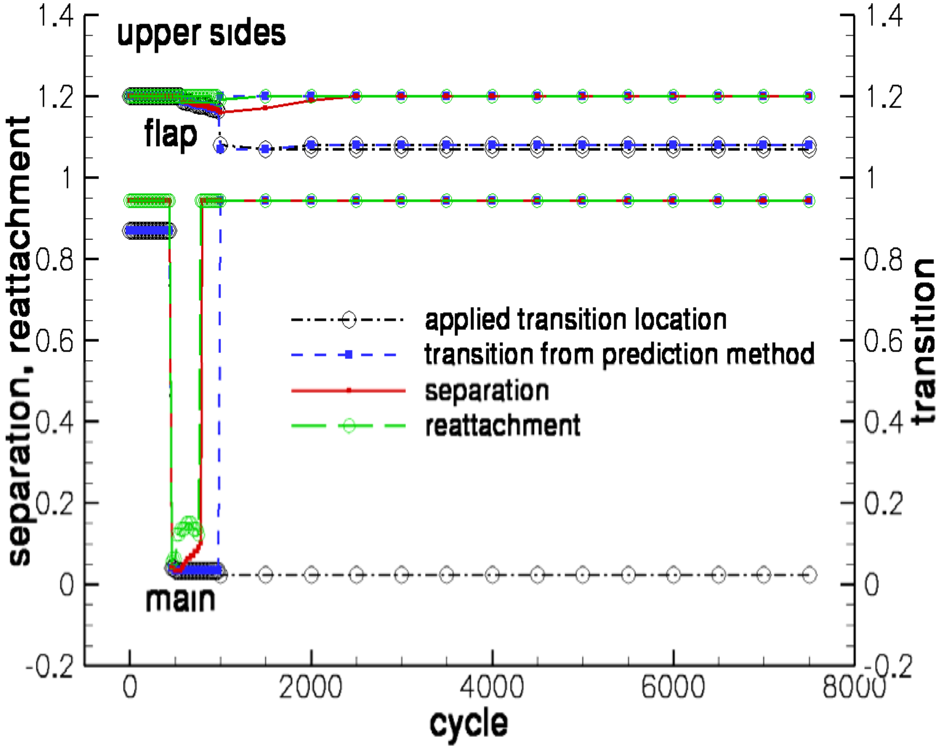
Transition iteration convergence history: BL mode 2, N = 5.8 *new*

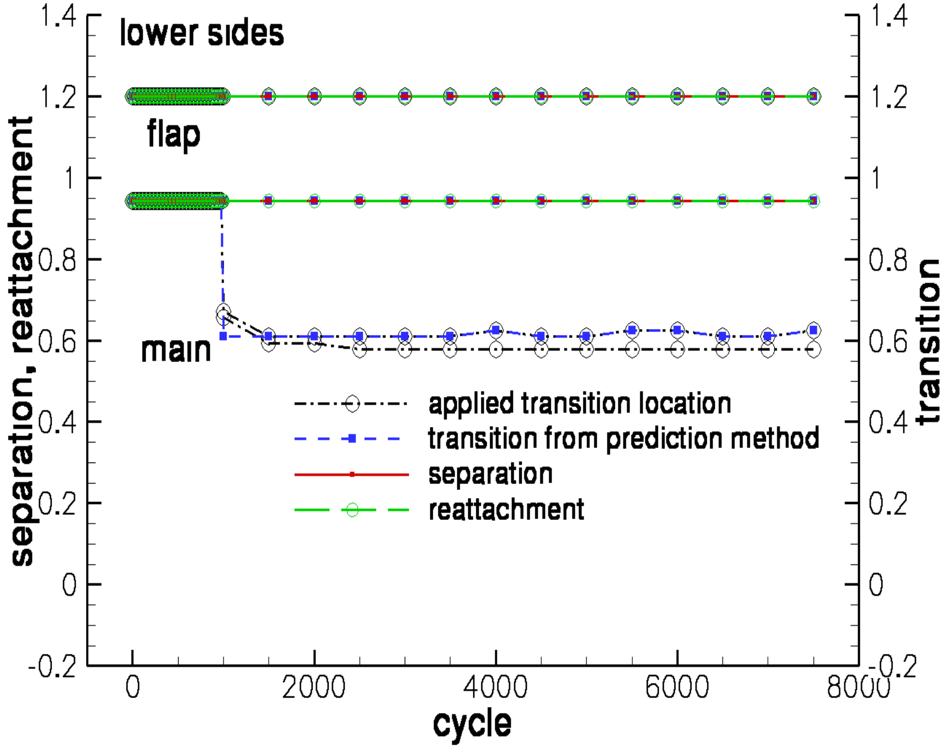


- **pre-prediction phase → 1,000 cycles**
  every 20 cycles
- **prediction phase → starts at cycle = 1,000**
  every *500* cycles

- **limited convergence**
- **1st numerical instability on flap**
  → small and acceptable
- **2nd numerical instability on main**
  → smaller, but still NOT damped

Transition iteration convergence history: BL mode 1, N = 5.8 *new*



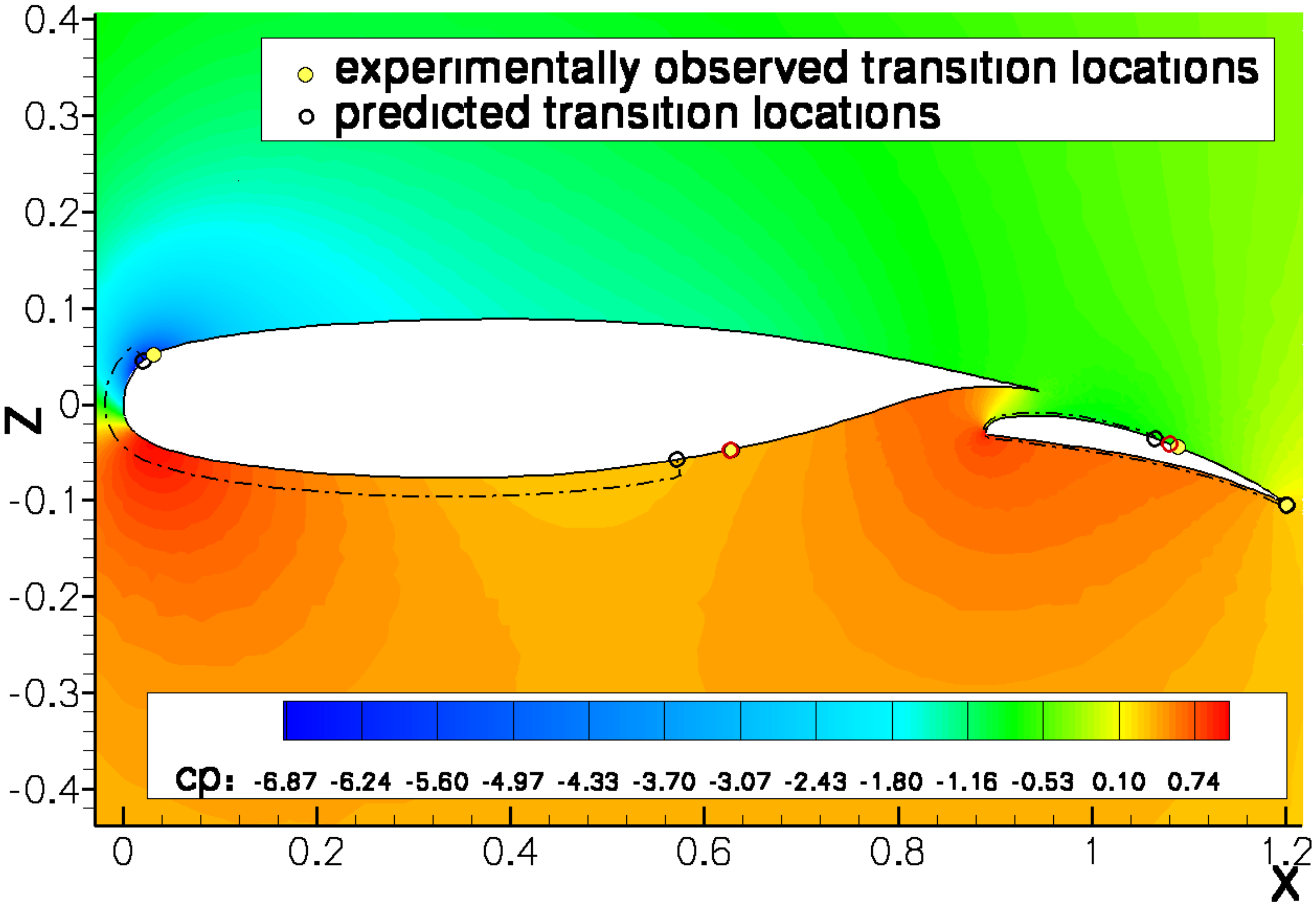


- pre-prediction phase $\rightarrow$ 1,000 cycles
  every 20 cycles
- prediction phase $\rightarrow$ starts at cycle = 1,000
  every *500* cycles

- very fast convergence

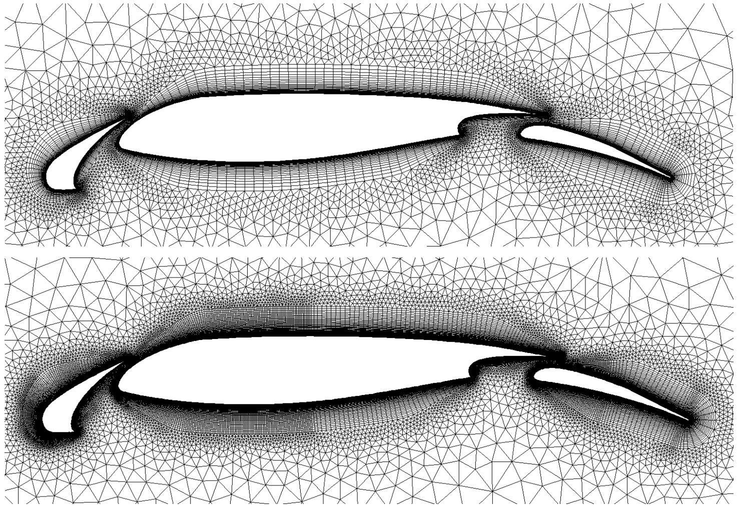
c_p-field and transition points: BL mode 1, N = 5.8, *new*

- *no* separation in final RANS solution
- *very good* approxi-mation of the measured transition points

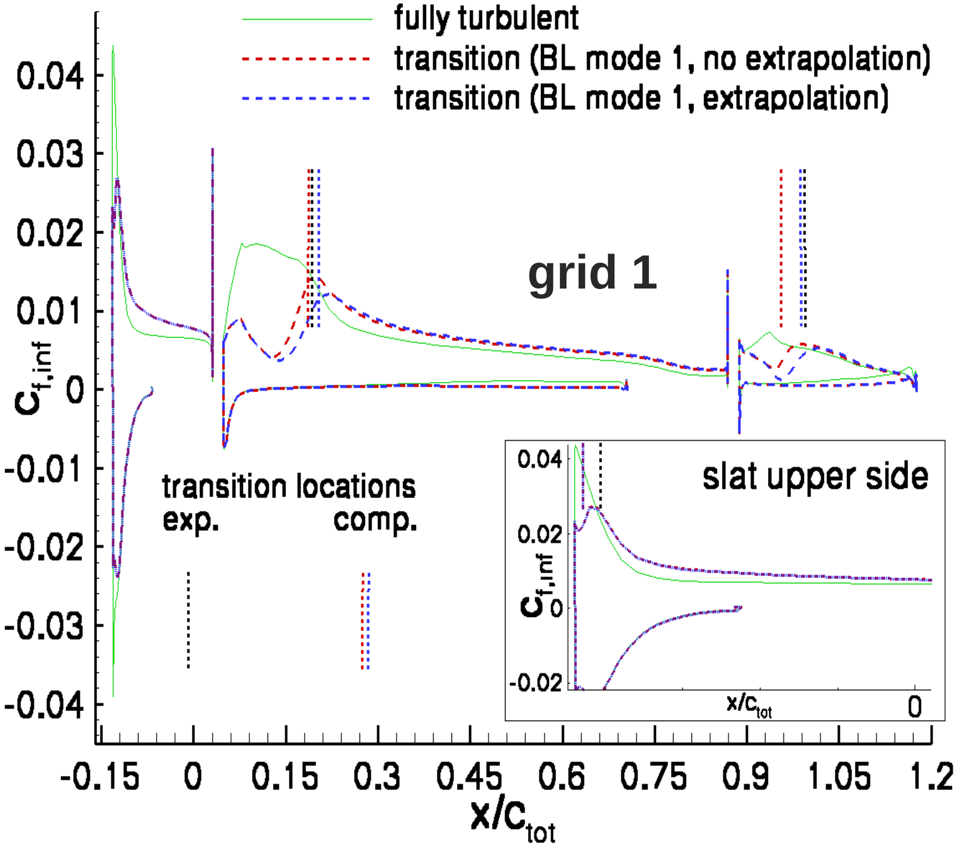


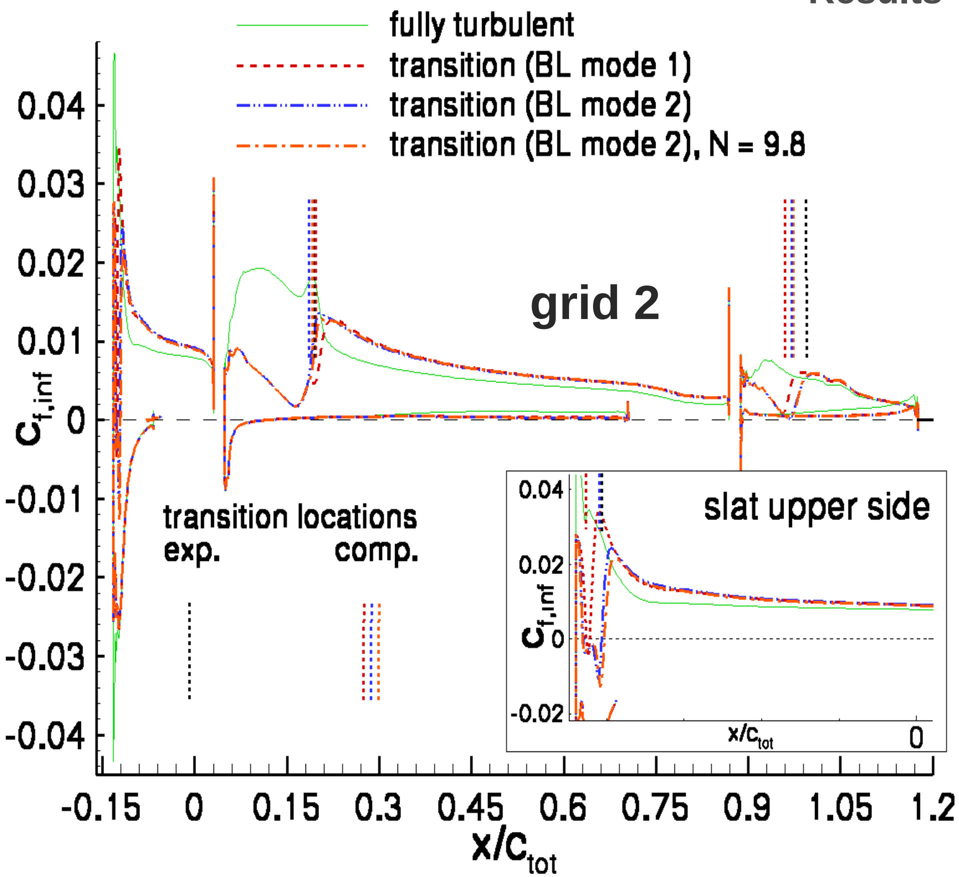
2d three-element configuration:

- M = 0.221, Re = 6.11 x 10^6, α = 21.4°
- grid 1: 22.000 points
  grid 2: 122.000 points, noses highly resolved
- SAE
- N_{TS} = 9
- prediction only on upper sides, lower sides fully laminar
- exp. transition locations → slat: 15% & flap: 34.5%
  'kink' on main upper side → 19%
- different mode combinations:
  a) laminar BL code & stability code → BL mode 1
  b) laminar BL inside RANS & stability code → BL mode 2



Grids: J. Wild, DLR





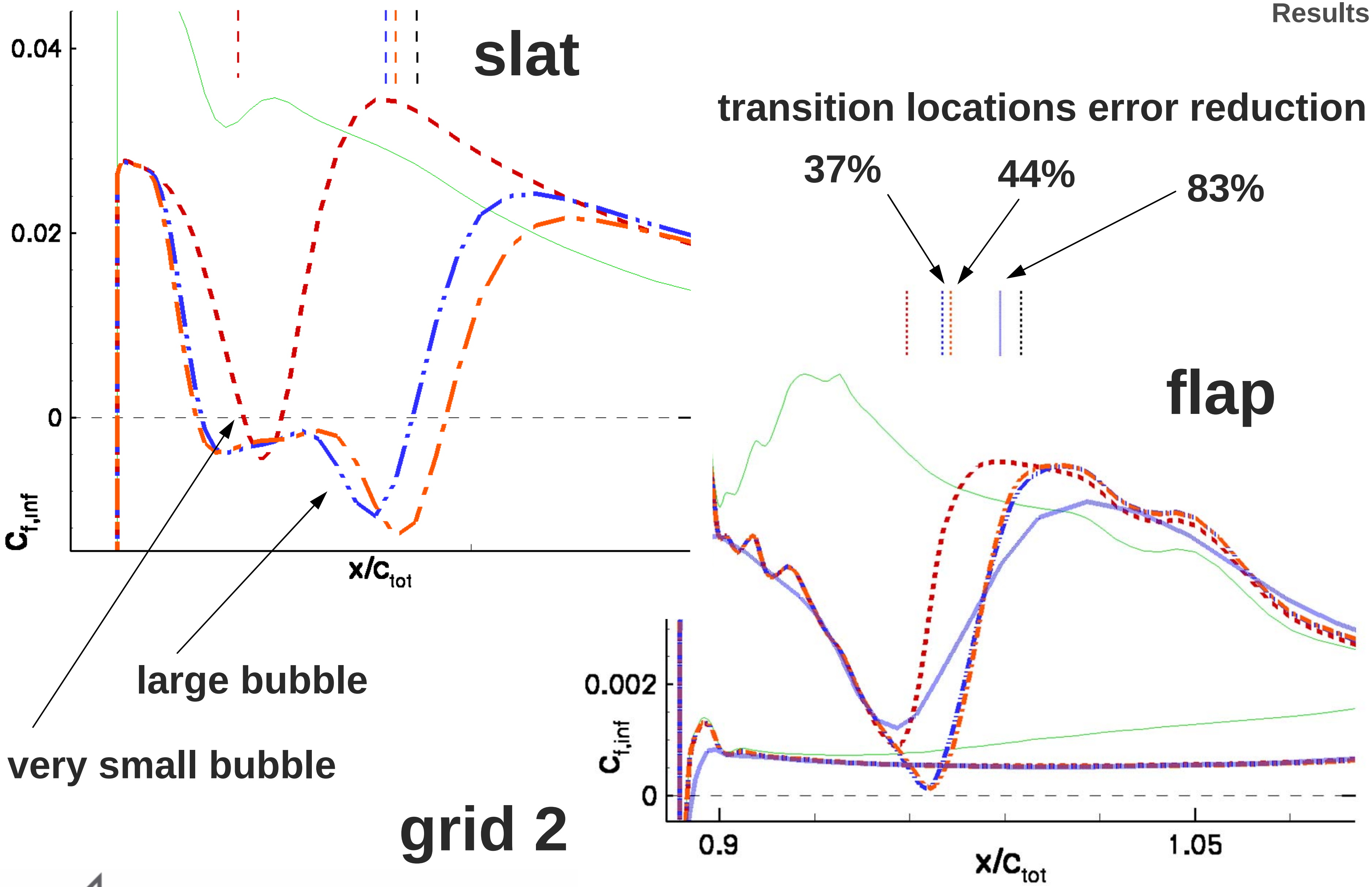
NO separation bubbles

transition locations: very good → flap

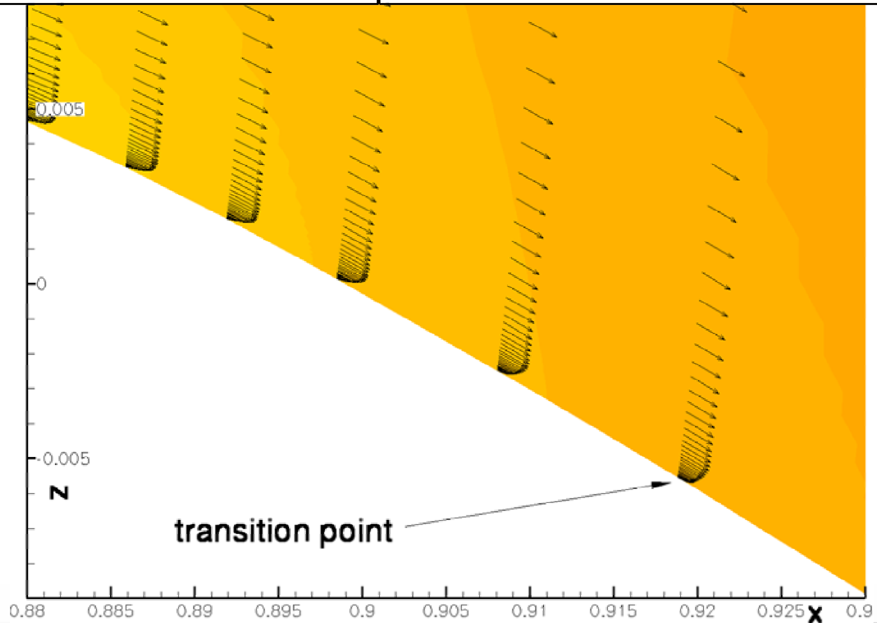
slat separation bubble

transition locations: very good → slat
good → flap

the higher N, the larger the bubble

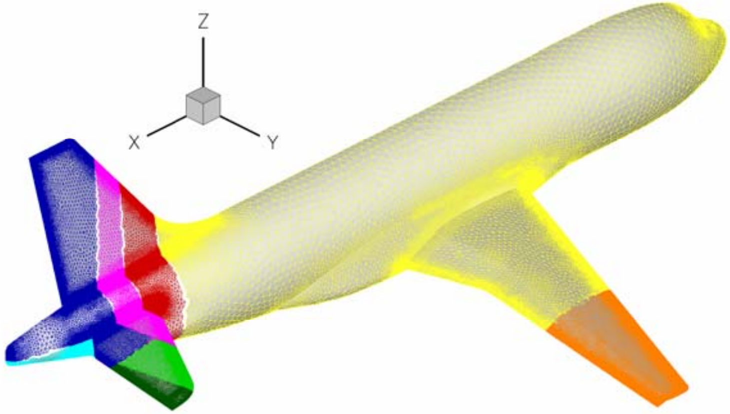

slat
0.04
0.02
0
$c_{f,inf}$
x/c_{tot}
large bubble
very small bubble
grid 2
transition locations error reduction
37%
44%
83%
flap
0.002
0
$c_{f,inf}$
0.9
1.05
x/c_{tot}

Results



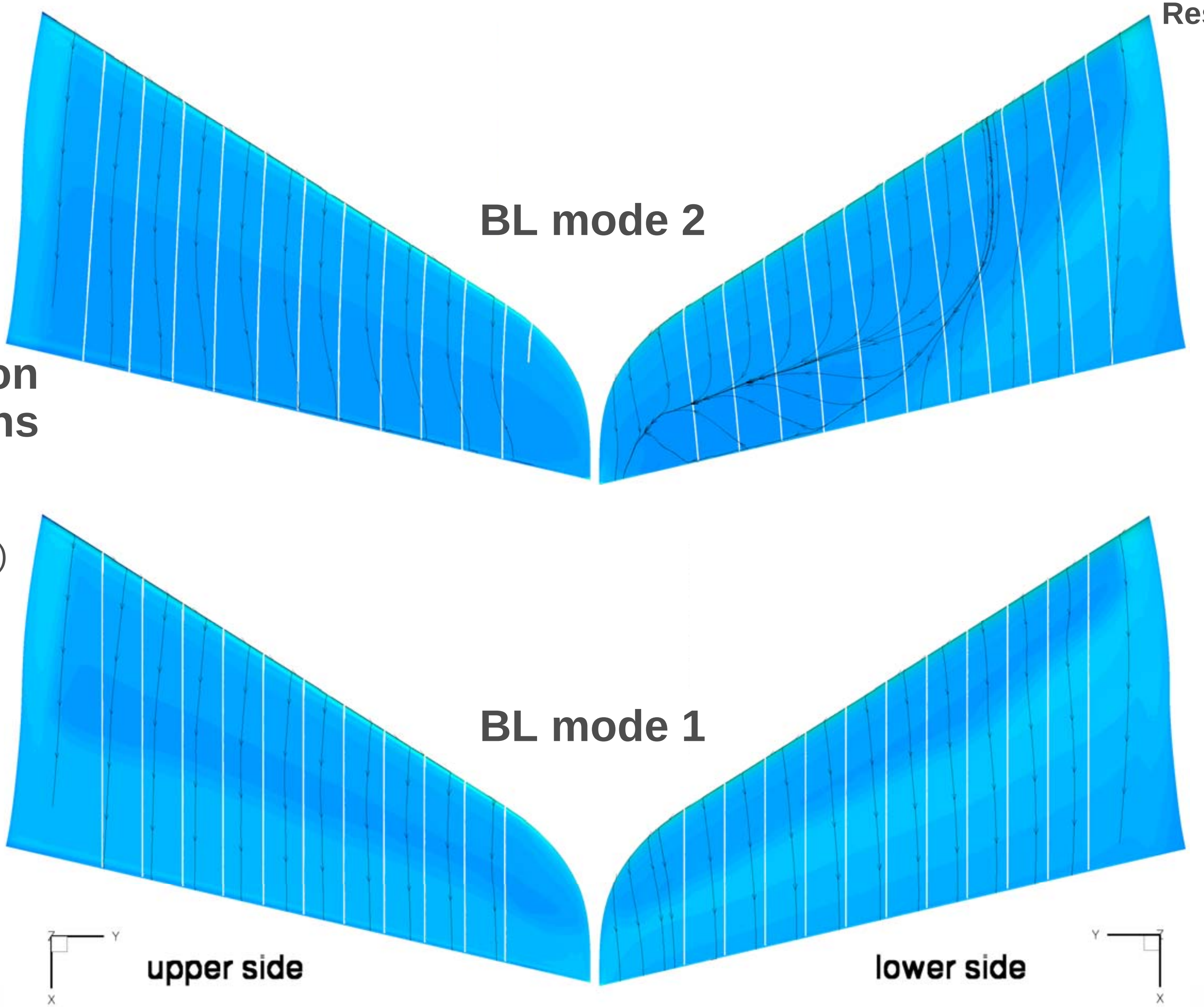
0.005
0
-0.005
z
transition point
0.88
0.885
0.89
0.895
0.9
0.905
0.91
0.915
0.92
0.925
x

3D generic aircraft configuration:

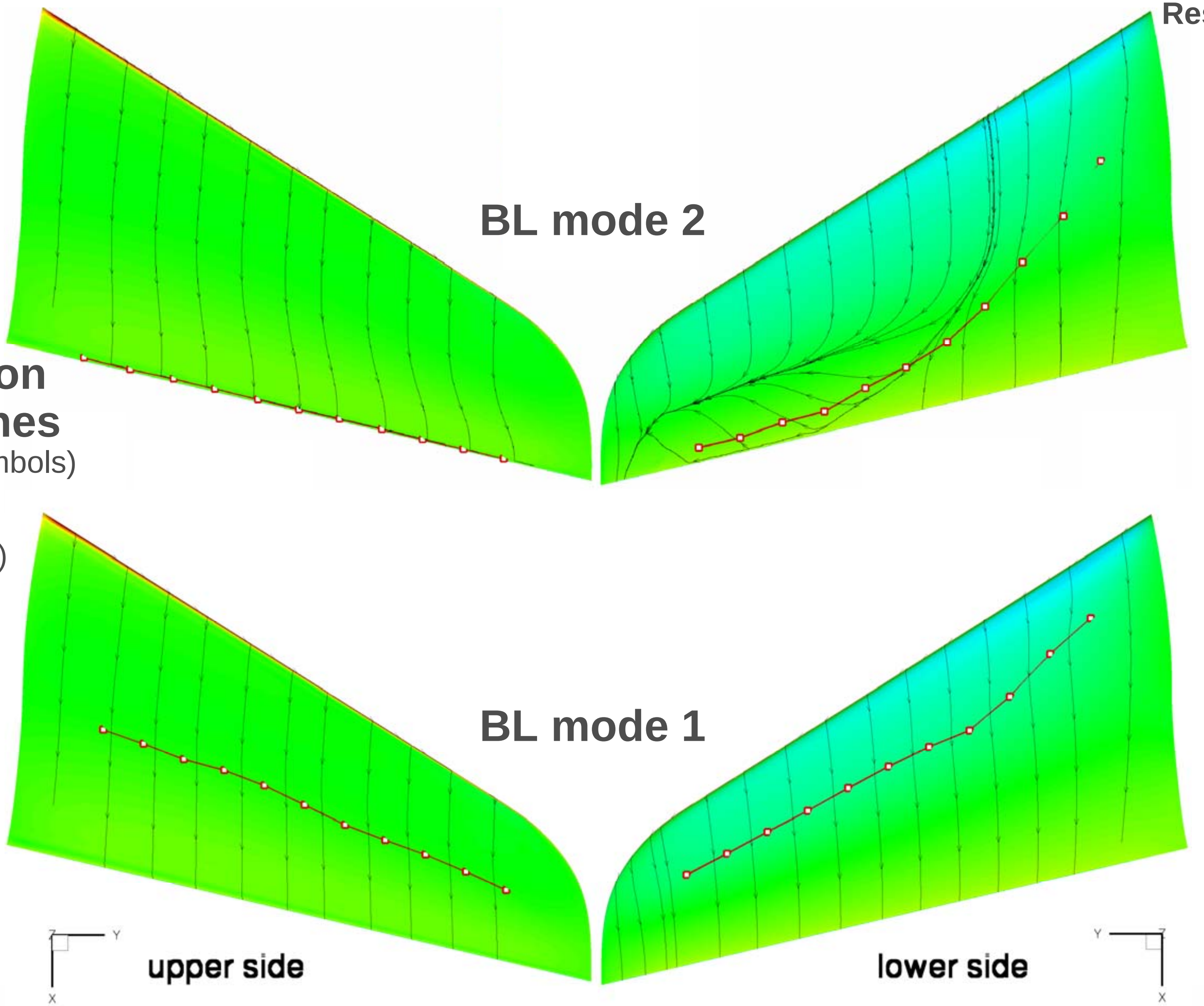


geometry: Airbus, grid: TU Braunschweig

- $M = 0.2$, $Re = 2.3 \times 10^6$, $\alpha = -4°$, $i_{HTP} = 4°$
- grid: • 12 mio. points
  • 32 cells in prismatic layers
  • at HTP: 48 cells in prismatic layers
- SAE
- $N_{TS} = N_{CF} = 7.0$ (arbitrary setting)
- transition prediction on HTP only, upper and lower sides
- different mode combinations:
  a) laminar BL code & stability code & *line-in flight cuts* → BL mode 1
  b) laminar BL inside RANS & stability code & *inviscid streamlines* → BL mode 2
- parallel computation: either 32, 48, or 64 processes
- 2.2 GHz Opteron Linux cluster with 328 CPUs



- c_f-distribution
- **wing sections** (thick white)
- **skin friction lines** (thin black)

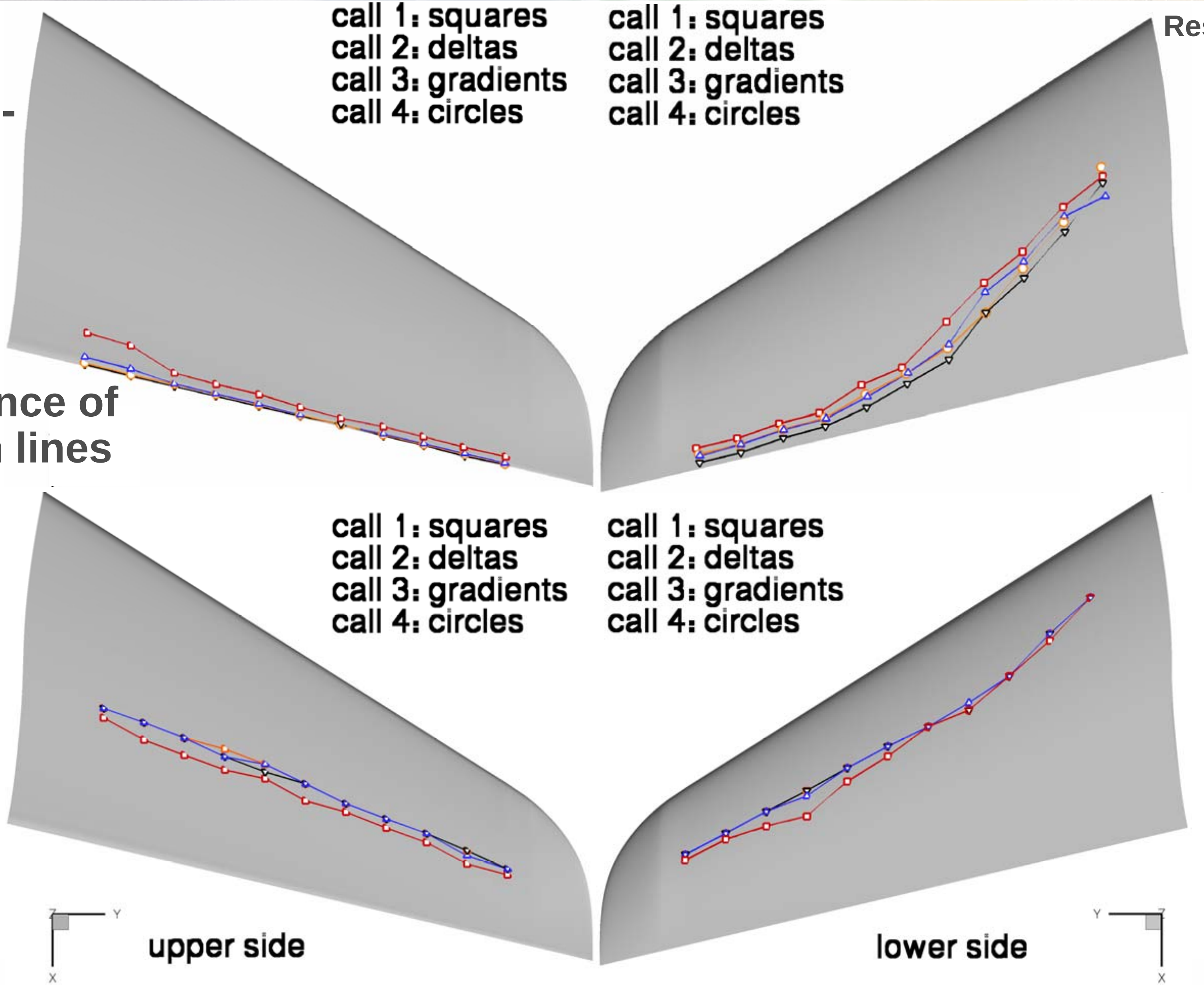


- c_p-distribution
- **transition lines** (thick red with symbols)
- **skin friction lines** (thin black)

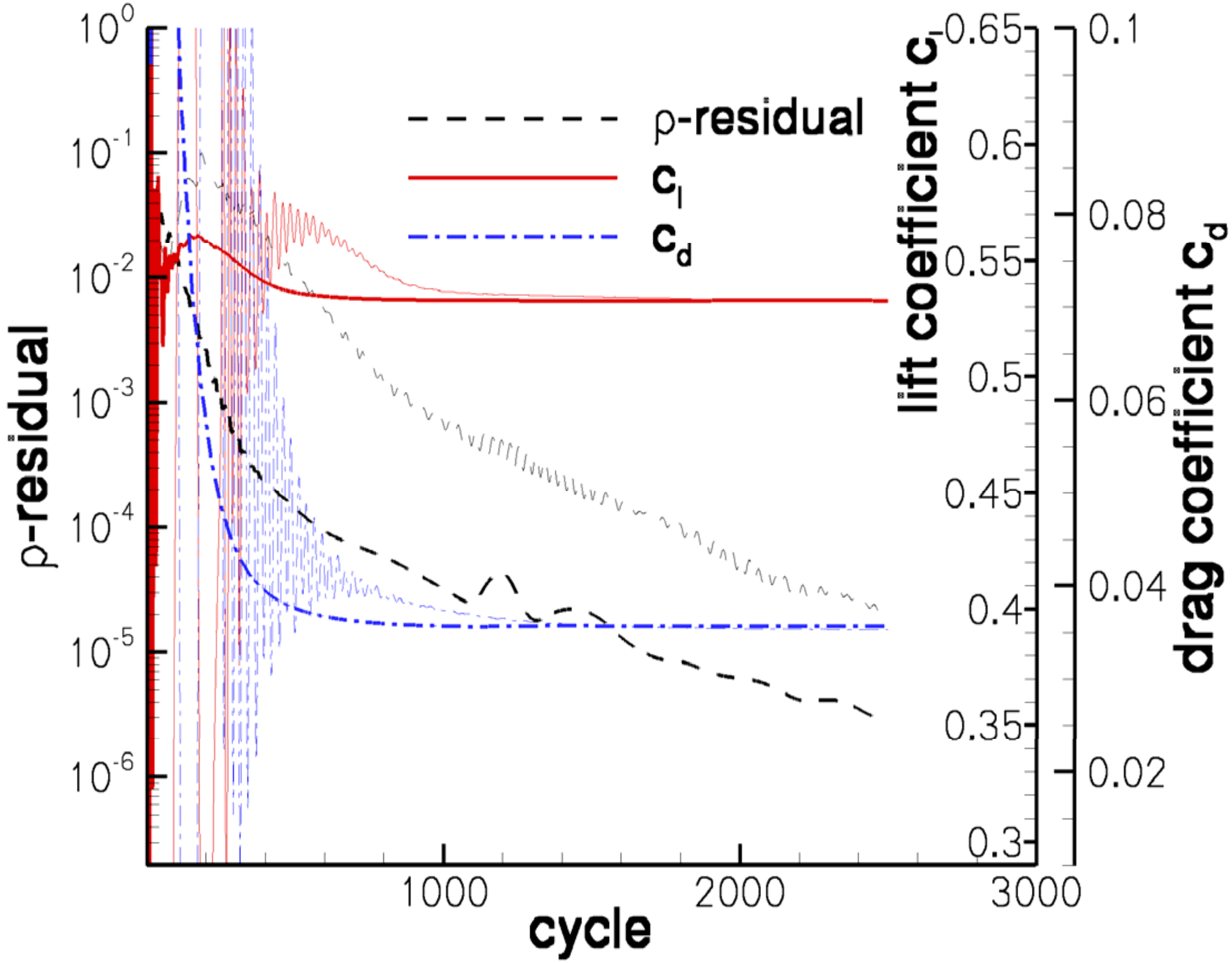
- pre-pre-diction until cycle:
  500
  every 20 cycles

- convergence of transition lines

  calls at cycles:
  500,
  1000,
  1500,
  2000
  out of 2500



- **convergence history of the coupled RANS computations:**



Conclusion and Outlook

- RANS computations with integrated transition prediction were carried out without intervention of the user.
- The transition tools work fast and reliable.
- Complex cases (e.g. transport aircraft) can be handled; experience up to now limited to one component of the aircraft.
- Use of lam. BL code leads to fast convergence of the transition prediction iteration; not always applicable, because transition may be located significantly downstream of lam. separation; extrapolation may help when amplified modes exist upstream of laminar separation
- Use of internally computed lam. BL data can lead to numerical instabilities when laminar separations are treated
  - → interaction between different separations can occur
  - → interaction of separation points and transition points: oscillation of separation can lead to oscillation of transition

  ⇒ automatic shut down of transition iteration individually for each wing section or component of the configuration necessary

- In the nearest future:
  - Much, much more test cases
    - generic aircraft case:
      - α variation
      - different *N* factors
      - transition on all wings of the aircraft
      - inclusion of fuselage
    - transonic cases
    - physical validation, e.g. F4, F6 (AIAA drag prediction workshop)
    - complex high lift configurations, e.g. from European EUROLIFT projects
  - Setup of Best Practice guidelines